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The effect of HEAT on the industrial worker

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Introduction

It is well recognized that the temperature of the body must be kept within relatively narrow limits if health is to be maintained. If men work in environments that are too hot, they experience discomfort and fatigue, their working capacity falls, errors in perception and judgment appear and eventually serious physiological disturbances may lead to exhaustion and collapse. Recognition of these facts leaves us with the problem of defining conditions which are too hot. That this is by no means a simple problem emerges from recent reviews by WEINER and LIND (1955) and by BEDFORD TREDRE (1955).

In the present paper, detailed descriptions of earlier work concerning the responses of men to work in heat are avoided, since these are available elsewhere, as indicated below. The intention is to outline the principles governing heat exchanges between the body and its environment, to evaluate results from recent investigations in this context, and to examine how existing knowledge may be applied to the industrial situation.

Bodily Heat Exchanges

Theoretical calculations. The sources of heat gain and heat loss to and from the body are, principally, (1) the body heat production which can vary greatly depending on the amount of activity undertaken, (2) convection and radiation, each of which can result in a heat gain or in a heat loss depending on whether the skin temperature of the body is below or above the temperature of the air and the surroundings, and (3) evaporation of sweat from the skin which can only result in heat loss from the body. Small heat exchanges may also occur by evaporation and convection through the lungs, by conduction, and by the ingestion of food and drink at temperatures above or below body temperature, but these normally represent such a small proportion of the total heat exchanges that they are customarily ignored.

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If the body is to maintain thermal equilibrium, then the amount of heat gained by work and from the environment must be offset by heat lost in equal amounts from the body to the environment. The body seldom maintains an exact equilibrium, however, and work performed even in cool climates is accompanied by a rise of body temperature (Neilson, 1938). This rise of body temperature is greater in climates that are too hot, and so far as the physical interpretation of heat exchanges is concerned, represents the storage of heat in the tissues of the body. During exposure to heat, therefore, the heat exchanges can be simply represented by the equation

$$M \pm C \pm R - E = S$$

where M is the heat produced by metabolism, C and R represent the heat gained or lost by convection and radiation respectively, E is the heat lost by evaporation, and S is the amount of heat stored in the body. If the body maintains thermal equilibrium, then S = O.

Studies in the thermal exchanges of the body, by Nelson, et al. (1947) resulted in the definition of the thermal coefficients for convection, radiation and evaporation. Thus equations to represent the heat exchanges through these channels can be expressed, for practical purposes, as

$$C = 0{\cdot}5V^{0.5}(ts - ta) \quad (1)$$

$$R = 5{\cdot}7(tg - ts) \quad (2)$$

$$E = 1{\cdot}4V^{0.4}(ps - pa) \quad (3)$$

where V is the air movement, ts, ta and tg are skin, air and mean radiant temperatures and ps and pa are vapour pressures on the skin and in the air. In these equations, thermal exchanges are expressed in units of kcal/m² per °C or mm Hg, with air speed in ft/min.

Recent experiments by KERSLAKE and WADDELL (1958), BREBNER et al. (1958a; 1958b) and CLIFFORD (1959) have confirmed the accuracy of these coefficients for convection and radiation, but showed that the coefficient for evaporation could be better expressed by the value of $0{\cdot}45V^{0.63}$, so that equation (3) above becomes

$$E = 0{\cdot}45V^{0.63}(ps - pa). \quad (4)$$

Heat storage in the body may be calculated by a formula proposed by BURTON (1935)

$$S = W \times 0{\cdot}83\,(0{\cdot}65\Delta tr + 0{\cdot}35\Delta ts) \quad (5)$$

where W is the weight of the individual and tr and ts are rectal and skin temperatures.

Detailed discussion of these theoretical calculations is not possible here, and may be found in the relevant papers quoted, and elsewhere (e.g. MACHLE and HATCH, 1947; BEDFORD and TREDRE, 1955). The equations given above refer to the calculation of heat exchanges on nude men, and are consistent with theoretical expectation. Results obtained from clothed men by NELSON et al. (1947) were understandably less satisfactory, since the determination of heat exchanges is complicated by the introduction of such difficulties as measurement of the emissivity and the heat capacity of the clothing worn. Nevertheless, there are possible practical applications of these equations as described below.

Factors affecting heat exchanges. A major source of difficulty in assessing the heat stress of most working conditions is the assessment of the effect of the many factors which influence heat exchanges between the body and its environment. The total heat load on the individual is the result of the interaction of many variables. In general, these variables may be considered separately as (1) climatic and (2) non-climatic factors.

The important climatic variables are the air temperature, humidity (usually represented by wet-bulb temperature), air speed and mean radiant temperature (represented by globe thermometer readings). Since all heat exchanges occur through the skin, these variables have to be considered in association with the temperature of, and the vapour pressure on, the skin. Convective heat exchanges are affected by the difference between air and skin temperature, and by the speed of the air over the skin, while those of radiation are influenced only by the difference between skin temperature and the temperature of the surroundings. Evaporative losses are affected by the amount of air movement and the difference in the vapour pressures of the skin and the surrounding air.

Non-climatic factors which can affect heat exchanges include purely physiological as well as non-physiological factors. The body heat production can vary considerably, from values at rest of about 70 kcal/hr, to about 350 kcal/hr during moderate rates of work, while during hard industrial work values of 500 kcal/hr or more may occur. If the body were otherwise unable to gain heat except from this source or to lose heat by any method, at the rates of work mentioned above, a 76 kg man (12 stone) would increase his body temperature at rates of about 1, 5.5 and 8°C/hr respectively (1·8, 9·9, and 14·4 °F/hr). In cool climates the body easily dissipates these amounts of heat, and even in the absence of heat gains from the environment, this is convincing evidence of the efficiency of the thermoregulatory system.

When clothing is worn, obviously the heat exchanges across the skin must be modified. Usually, an increase of clothing in hot climates adds to the total heat stress imposed on the subject (cf. MCARDLE et al. 1947). This becomes particularly true when clothing of increasing impermeability is worn, where the evaporation of sweat can be seriously restricted or completely prevented, and the individual is subjected to a hot environment with a high level of humidity inside the suit due to the evaporation of sweat. When there is a high radiant heat load, however, clothing may be utilized to protect the individual.

When men are first exposed to work in hot climates, they usually experience lassitude or even discomfort. Repeated exposures result in the reduction or abolition of these symptoms, and men are able to work more efficiently. This process of acclimatization is accompanied by physiological adaptions whereby progressive reductions in the increments of skin and rectal temperatures and pulse rate and an increase in the amount of sweat loss can be readily demonstrated (e.g. BEAN and EICHNA, 1943; ROBINSON et al. 1943). Acclimatization has also been shown to be associated with a more efficient circulation WYNDHAM, 1954; HELLON and LIND, 1955) which helps the transfer of heat from deep tissues of the body to the skin. HELLON et al. (1956) showed that the physiological basis of "natural" acclimatization resulting from living in the tropics is identical with that of "artificial" acclimatization produced in the laboratory by exposure to heat daily for short periods. The processes of acclimatization are virtually complete in two weeks.

Despite the large number of investigations into the mechanisms involved in acclimatization, little is known of the amount of benefit so derived, in quantitative terms; some information which is available from African subjects examined by WYNDHAM et al. (1954a) in saturated climates suggests that after acclimatization, similar performances to those obtained before acclimatization, were found in climates 1·7-3·3 °C (3-6 °F) higher.

There is some evidence to suggest that other factors might also affect heat exchanges although the extent of the influence of any of these factors is as yet unknown. HELLON, et al. (1956b) and HELLON and LIND (1956, 1958) have shown that with increasing age, the sweat glands respond more slowly to an increase in heat load, and that the body supply through the skin is in excess

of that required for thermoregulation. Obesity, presenting greater superficial insulation to the transfer of heat from the deep tissues of the body, might also be expected to be detrimental to the individual working in hot climates. Mild illness might also be expected to be undesirable, as reported briefly by WYNDHAM et al. (1954b) and by LIND et al. (1957), although this view is not entirely supported by MACPHERSON (1959). Physical "fitness" may also affect the responses of the individual to work in heat. While few observations have been made, presumably partly because of the difficulty of defining "fitness", BEAN and EICHNA (1943) noticed that men who regularly took exercise became more effectively acclimatized to heat than men who took little or no exercise.

The influence of some of the factors mentioned can be assessed, and although there is so far little information available concerning the other factors, recognition of their existence at least allows the exercise of caution.

Heat Stress Indices

Many attempts have been made to evaluate the total heat stress on man by integrating some of the factors which affect heat exchanges into a single index. BEDFORD (1948) and BEDFORD and TREDRE (1955) have described and have discussed the comparative merits of many of these indices. It is intended here only to consider briefly the three scales which are best known, and to discuss recently published observations concerning the accuracy of these indices.

Effective Temperature scales. The effective temperature scales were devised originally as scales of comfort by HOUGHTEN and YAGLOGLOU (1923) and were later considered to be a good physiological index of stress (e.g. YAGLOGLOU 1927). In the original scales the subjective comfort of any combination of dry- and wet- bulb temperatures and air movement could be assessed, using as a reference the still, saturated environment in which the immediate sensations of warmth experienced were identical with those experienced in the test climate. BEDFORD (1946) proposed the use of globe thermometer readings instead of air temperature readings to make allowance for radiant heat, and the scales became known as the Corrected Effective Temperature scales. Two scales are available, one referring to men stripped to the waist and the other to men fully dressed in indoor clothing.

Many series of experiments have shown shortcomings in the scales when they are applied to men working at rates ranging from moderate to hard, in heat. ROBINSON et al. (1945), EICHNA et al (1945) and BENSON (1945) all reported that the scales exaggerate the stress imposed by high dry-bulb temperatures when the air movement was about 100-300 ft/min. DUNHAM et al. (1946) showed that the scales do not give sufficient weight to the deleterious effect of low air movements in hot and humid environments. Data from experiments by EICHNA et al. (1945), ELLIS et al. (1953b) and LIND et al. (1957), where very severe conditions of heat stress were examined, showed that climates of similar severity as judged by rectal temperature, pulse rate, weight loss and tolerance time, do not correspond to the same Effective Temperature.

It remained arguable that since the Effective Temperature scales were devised from data obtained from seated men and from men engaged in only light activity, it was not unreasonable that results obtained from men performing moderately hard work do not conform to the predictions of the scales.

To test the validity of the scales in severe environments when the metabolic conditions approximated to those from which data were collected for the construction of the scales, LIND and HELLON (1957) submitted resting, nude men to eight different climates. These experiments showed that different climates with the same Effective Temperature did not result in the same physiological stress as judged by tolerance times, rectal temperatures, pulse rates, skin temperatures, sweat loss and forearm blood flows. (Comparison of some of these data with Effective Temperature can be seen in Fig. 1.) The scales proved inadequate as a method of predicting the relative severity of the climates investigated,

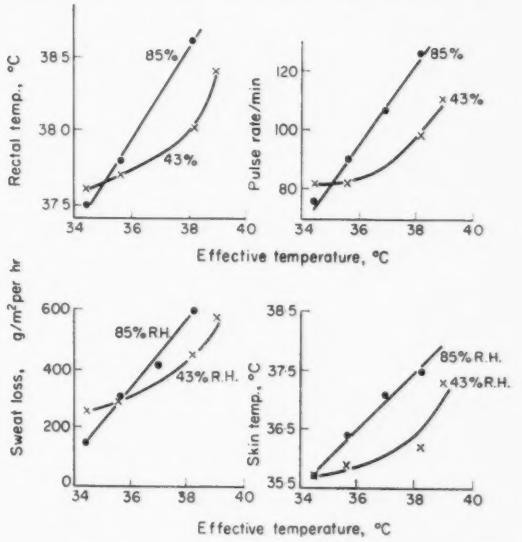

FIG. 1. The mean physiological responses of nine seated, nude men after 1 hr exposure to four humid climates (●) with 85 per cent relative humidity, and four drier climates (×) with 43 per cent relative humidity. It is clear that with increasing severity of the climates the Effective Temperature values do not correlate with the physiological responses.

although this was less marked in the more moderate environments, supporting SMITH'S (1955) view that the scales may be reasonably accurate in warm climates where the heat stress is less. Recently, BREBNER et al (1958b), also examined results from seated, nude men in hot climates and endorsed the conclusion that the Effective Temperature scales were misleading at high stress levels.

It is clear that there is an inherent error in the construction of the Effective Temperature scales which leads to inaccurate evaluation of the physiological effects induced by exposure to climates of high heat stress.

Predicted four-hourly sweat rate (P4SR). The P4SR scale, devised by MCARDLE et al. (1947), represents the heat stress of an environment in terms of the sweat produced in four hours. The scale allows for wide variations in dry and wet-bulb temperatures, globe thermometer readings, air movement, clothing worn and the rate of work. This index was devised from data obtained from over 1000 experiments. Results from later experiments led to the conclusions that (1) there was no difference in the results obtained by MCARDLE et al. (1947), from "artificially" acclimatized men living in London, and those obtained from men naturally acclimatized to work in the tropics (e.g. ADAM et al. 1952), and (2) that the scale made accurate allowance for the effects of radiant heat (FERRES et al. 1954a).

The intentions of MCARDLE et al. (1949) in the construction of the P4SR index were not simply to allow the estimation of the amount of sweat produced in given conditions, but to provide a measure

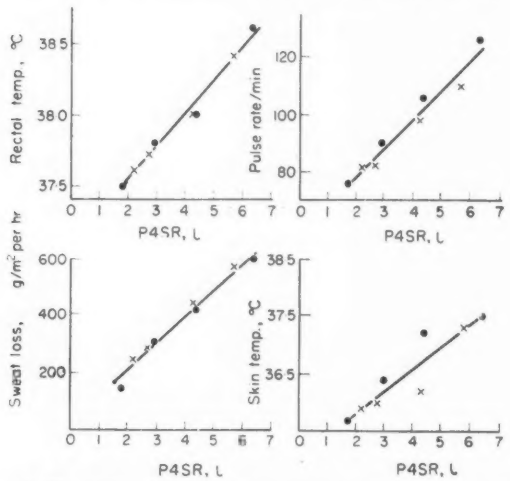

FIG. 2. The mean physiological responses of nine seated, nude men after 1 hr exposure to four humid climates (●) with 85 per cent relative humidity, and four drier climates (×) with 43 per cent relative humidity. The results, which are the same as those shown in Fig. 1, correlate well with the P4SR values, and serve to show the relative accuracies of the E.T. and P4SR scales as measures of physiological response to high degrees of heat stress.

of heat stress. Thus, a working condition with a P4SR of 4·0L is always of greater stress value than one of 3·9L, irrespective of whether the amount of sweat produced by a group of men in the first condition is more than they produce in the other climate. That is, the authors of the index do not commit themselves irrevocably to the belief that sweat rate is necessarily allied to the heat stress, although if one single physiological measurement has to be used, the sweat rate has much to commend it.

Comparison of experimental results with the P4SR values has led to a gradually accumulating body of support for the index. WYNDHAM et al. (1953) concluded that it was rather more accurate than the Effective Temperature scale. WYNDHAM (1954) also found a good relationship between circulatory measurements in different climates and the P4SR scale values for those climates. LIND and HELLON (1957) found that the P4SR scale accurately predicted the order of severity of different climates for seated, nude men, when the Effective Temperatures scales failed to do so. The physiological data obtained in these experiments correlated well with P4SR values as can be seen in Fig. 2. These data are the same as those shown in Fig 1, and therefore provide a clear indication of the relative accuracy of the P4SR and Effective Temperature scales in conditions of high heat stress. Similarly, BREBNER et al. (1958b) found that while the Effective Temperature scale did not provide a satisfactory measure of environments of equal heat stress, the P4SR scale was in good agreement with the observations.

Although the P4SR scale is rather more complicated to use than the Effective Temperature scale, and the use of sweat rate as a measure of heat stress may be unfamiliar to many, there is a growing body of information to show that the scale accurately assesses the severity of different combinations of work, clothing and climate in terms of physiological response; the P4SR index appears to be the most successful method, so far available, of estimating the heat stress of a given working condition.

The Belding-Hatch index. HAINES and HATCH (1952) adapted the heat balance equation to the assessment of heat stress, and this method was further elaborated by BELDING and HATCH (1955) to include a numerical index of the stress imposed by given conditions of work and climate. The method is based on a comparison of the amount of sweat required to be evaporated ("evaporation required") to maintain thermal equilibrium, and the maximum amount of sweat which can be evaporated in the specified climatic conditions

("maximum evaporate capacity"). The ratio of these two factors is the heat stress index of a given set of conditions. Thus this index, like the P4SR index, depends on sweat production to provide the assessment of heat stress.

If the equations defined by NELSON et al. (1947) and KERSLAKE and his colleagues (1958, 1958a, 1958b, 1959) are to be used for accurate analysis of heat exchanges, it is necessary to know skin and rectal temperatures and the height and weight of the subjects as well as the climatic conditions and the rate of work. In order to simplify the calculations to a manageable level, and to allow the procedure of analysis of heat exchange to be useful as a predictive index it was necessary for BELDING and HATCH to make a number of assumptions and approximations. For the purposes of the index they assumed a fixed surface area of the body, a fixed level of skin temperature, that heat exchanges through the lungs could be safely ignored, and that there is no storage of heat in the body.

HAINES and HATCH (1952) demonstrated that this adaption of partitional calorimetry could be useful in industry to decide which were the most important avenues of heat gain or loss in given conditions, thereby more easily allowing the application of corrective measures. From the results of a controlled laboratory experiment FERRES et al. (1954b) compared the heat exchanges calculated from the modified formulae suggested by HAINES and HATCH (1952) with those calculated from the formulae of NELSON et al. (1947) and found, for instance, discrepancies of from 19 to 45 per cent in the "maximum evaporative capacity" derived from the two methods, when working men were exposed to heat stresses of moderate severity. Differences of this sort would imply that, while the accuracy of this technique might not be seriously affected by any one of the assumptions or approximations mentioned above, it is dubious whether the collective effect of all of them allows the index to be sufficiently accurate for general use. The evaporative coefficient recently described by GIFFORD et al. (1959) may confer greater accuracy to the index, although this possibility has not yet been examined.

Other indices have not yet been considered here, on the grounds that they are either of more limited value or that they are not readily applicable to the practical situation. There can be little doubt that physiologists would favour the use of the P4SR scale as a measure of heat stress and as a predictive index, although other scales may be considered useful if they are applied to circumstances for which they were intended and with a full realization of their limitations.

One of the important uses of heat stress index is the definition of "limiting conditions" of heat. Obviously, the interpretation of "limiting conditions" will vary according to the purpose for which the limits are required; for instance the heat stress to which men may be exposed during emergencies can be more severe than that which is considered acceptable for every day work. It is convenient, then, to consider in turn three interpretations of the "limiting conditions" of heat.

Upper tolerable thermal limits. The phrase "upper tolerable thermal limits" is taken here to mean those climates in which men can just perform some known task for a given length of time without suffering heat exhaustion and collapse.

The results from different investigations intended to specify "upper tolerable thermal limits" show quite good agreement when variations of the conditions of work, clothing and climate are taken into account. EICHNA et al. (1945) ROBINSON et al. (1945), and ELLIS et al (1953a) all described "upper tolerable thermal limits" which agree well with a P4SR value of 4·5L, suggested by MCARDLE et al. (1947) as the limit above which an increasing number of men would find the conditions beyond their endurance. These limits are supported by observations such as those of CAPLAN (1943), who found after many years of experience that heat casualties in the Kolar Gold Field in India seldom occurred at wet-bulb temperatures lower than 32.7°C (91°F) when air temperatures were between 43.3°C (110°F) and 48.9°C (120°F). All these results apply to fit, young, acclimatized men engaged in tasks of moderately hard work. There is no direct experimental evidence to show what the environmental limits would be for men performing different rates of work, but the good agreement between existing experimental results and the P4SR value of 4·5L encourages the belief that the P4SR value of 4·5L would be similarly accurate for other work rates. It may be reasonably concluded that by this method the "upper tolerable limits" can be described for any given condition of work and clothing to which fit, young, acclimatized men are to be exposed. As explained earlier it is difficult to make allowances for variations in age, fitness and acclimatization. But in most cases of such severe heat exposure, special circumstances doubtless prevail and the men to be exposed will most often be selected and trained for work in such environments. To this extent, it is less important to know what allowances should be made for these variables; where older, less fit and less acclimatized men have to be exposed to severe heat stress, great care should be exercised and advice sought.

Duration of exposure in intolerable climates. Fewer experiments have been performed to define

the length of time that men can continue to work without fear of exhaustion or collapse ("tolerance time") in very severe environmental conditions. BLOCKLEY and TAYLOR (1950) and BLOCKLEY and LYMAN (1950) described the duration of exposure of young men, clad in union-suits, to dry air temperatures between 71°C (160°F) and 113°C (235°F) as between 12 and 90 min. Severe environments of this type are infrequently to be met in industry and the problem of protecting men in such conditions is more conveniently solved by the use of ventilated suit assemblies, as described below.

ROANTREE (1950) made a valuable contribution resulting from his observations on teams of men engaged in fire-fighting underground in Mysore; he was able to give a chart relating the permissible length of time for such workers with wet-bulb temperatures. This information referred to highly acclimatized men and could not be applied to rescue personnel in this country.

More recently, the National Coal Board initiated an intensive series of experiments to determine the "safe" durations of exposure for personnel engaged in mine-rescue operations (LIND et al. 1957). Thirty-six volunteers from the mine-rescue service performed a simulated mine-rescue operation in a wide variety of climates, saturated and non-saturated, and the times taken to achieve a rectal temperature of 38·8°C (101.8 °F) were noted. This value was chosen as a rectal temperature which indicated the presence of a high heat stress, and above which an increasing number of men may be expected to suffer heat exhaustion and collapse (e.g. ELLIS et al. 1953a). Observations on the visual vigilance of these men were also made, the results of which supported the "safe" durations of work in a wide variety of climates recommended on the basis of the physiological data. The duration of the hard work in hot climates was rather longer when the men wore one type of self-contained breathing apparatus than with another, owing to differences in the temperature of the inspired air (LIND, 1955) but no differences in the duration of work could be attributed to age or to occupation. This is not surprising since mine-rescue personnel are carefully selected and highly trained; nevertheless in another series of experiments (HELLON et al., 1956) the same men showed small but distinct differences in sweat production and in the blood flow to the skin, associated with ageing, when they were exposed for a longer period to carefully controlled conditions of work in heat.

As a result of these experiments tables were drawn up to specify the permissible duration of work for personnel engaged in rescue operations underground, and these tables (e.g. Table 1) have been adopted for use by mine-rescue services in this and other European countries.

TABLE 1. SHOWING THE TIMES MEN WEARING A SELF-CONTAINED BREATHING APPARATUS (USING LIQUID AIR AS ITS SOURCE OF OXYGEN), MAY BE EXPECTED TO WORK SAFELY ON A "MINE-RESCUE TASK" IN DIFFERENT ENVIRONMENTS.

Wet-bulb (°F)	Dry-bulb (°F)								
	80	85	90	95	100	105	110	115	120
					Safe	period	(min)		
72.5	—	—	—	—	—	—	—	—	69
75.0	—	—	—	—	—	72	70	68	65
77.5	—	—	—	72	67	65	64	63	59
80.0	72	72	67	64	61	59	57	55	52
82.5	—	63	60	57	55	53	51	48	46
85.0	—	55	53	50	48	46	44	42	41
87.5	—	—	47	45	44	41	38	36	35
90.0	—	—	41	39	38	35	33	32	31
92.5	—	—	—	33	32	31	30	30	26
95.0	—	—	—	30	28	26	26	24	24
97.5	—	—	—	—	26	24	22	22	
100.0	—	—	—	—	22				

Several other points of interest emerged from these experiments: (1) the Effective Temperature scale was found to be grossly inaccurate as a means of identifying climates of similar physiological effect, as has been discussed above, (2) the combinations of work, clothing and climate were so severe that they lay outside the range of the P4SR scale, (3) a simple formula, 0·85 wet-bulb temperature +0·15 dry-bulb temperature, proved to be sufficiently accurate for these practical purposes, to relate climates of similar physiological effect, within the range of conditions investigated.

The results obtained apply only to specific conditions, and because of the severity of the conditions and the danger which might be introduced by small errors, it would be unwise to extrapolate them to conditions outside the range of this investigation.

Permissible environmental limits for everyday work. While in special circumstances men may be allowed to work in "upper tolerable climatic conditions", they cannot be expected to continue to do so daily over a number of years without incurring the danger of ill health due to heat. It becomes necessary, therefore, to consider what are the environmental conditions in which everyday industrial work can be carried out by any individual over many years. Little experimental work has been carried out with the intention of defining such thermal limits; such observations as exist are primarily concerned with mining. The following

discussion is consequently concerned with this problem as it affects the miner, but any conclusions are likely to apply, with modifications, to men engaged in heavy duties in other industries. The following views emerged from discussions on this problem between my colleague DR. J. S. WEINER and myself.

In a number of countries in Europe and the Commonwealth, agreements exist stipulating the permissible thermal environmental conditions in mines within which men may be expected to produce a full day's work, and above which the duration or the rate of work must be restricted. Many of the agreements (only some of which are statutory) were formulated early in this century when present-day underground conditions were not envisaged, and when knowledge of the responses of men to exposure to heat was limited. As mines are driven deeper (and consequently, the underground thermal conditions are potentially worse) the necessity for setting realistic thermal limits on some objective physiological and psychological basis is pressing.

Although a great deal of information from the laboratory is available on the reactions of men to heat, it refers mainly to exposures of up to four hours daily for periods of up to five months, and was obtained from experiments designed specifically to meet the needs of the armed services in Britain and America. The dangers of direct application of such data to the practical situation have been emphasized before (WEINER and LIND, 1955), since the conditions of these experiments bear little relationship to the conditions of exposure underground (e.g. in the rate of work and the duration of exposure). It is clear that permissible environmental limits for use underground cannot be established until information has been gathered from experiments designed to suit the mining situation.

Some measure of the difficulties facing physiologists in this problem may be reflected in the limits suggested in recent years by different authorities. Four suggestions are shown in Table 2, three of which refer to mining, while the fourth was put forward by the Medical Research Council for use in the Royal Navy; of these, the most soundly based figures for permissible working conditions are probably those put forward for use in the Royal Navy. The terms "practical limit" "restricted limit" and "absolute limit" refer respectively to conditions in which normal work may be expected, to conditions in which the duration or the rate of work ought to be restricted, and to conditions in which only special work may be undertaken by agreement with the authorities concerned. The Effective Temperature scale has been accepted for use here because it is mainly in these terms that the recommendations shown were published and because in the range of use suggested for "practical limits" the scale may be considered to be reasonably accurate. For reference purposes, the "practical limit" shown for use in the Royal Navy has a P4SR value of 3L.

The levels at which thermal limits are set must clearly depend on the overall conditions of work to which they refer, taking into account all the factors which might affect heat exchanges between man and his environment. Obviously, for instance, the more the rate of work is increased, the less severe will be the conditions in which that work may be continued. It is necessary, therefore, to define the conditions to which thermal limits apply. This may be illustrated by defining the conditions to which the Royal Navy limits (shown in Table 2) apply. They refer to naval personnel whose upper age limit is about 50 years (80 per cent of the personnel are under 40 years of age), dressed in shorts, acclimatized to working in heat for 4 hr at an average energy cost of 110 kcal/m²/hr, when the posture, the pattern and type of work are all favourable. The environment in which men re-

TABLE 2. SHOWING SOME RECENT SUGGESTIONS PUT FORWARD BY VARIOUS AUTHORITIES AS POSSIBLE THERMAL LIMITS FOR EVERYDAY WORK. THE THREE LIMITS LABELLED "PRACTICAL", "RESTRICTED" AND "ABSOLUTE" ARE DEFINED IN THE TEXT.

Source	Occupation	Proposed thermal limits		
		Practical	Restricted	Absolute
Germany (1955)	mining	E.T. 27°C	E.T. 27–31°C	E.T. 31°C
Belgium (1947)	mining	—	—	E.T. (Belgium) 31°C
S. Africa (1953)	mining	E.T. 30°C	E.T. 30–32°C (for continuous light work)	E.T. 34°C
Britain (1952)	Royal Navy	E.T. 27°C	E.T. 27–32°C	E.T. 33.5°C

cover from heat exposure may be warm. If the limit suggested for use in the Royal Navy is accepted as an accurate one, it is possible to deduce the zone of climates in which a mining limit has to be set, by examining the difference between the working conditions for which these limits were set, and those found in mining, as shown in Table 3. Many of the factors which might affect the limits have been listed and specified, as far as possible, for each occupation, and in the extreme right-hand column is shown the probable effect that differences in these factors might have on the limits set for use in the Royal Navy. No reference has been made here to the decrement of psychomotor performance. Such information is important, but it is uncertain how accurately MACKWORTH'S (1950) findings, supported by PEPLER (1951), that performance deteriorates in psychomotor tasks above

hoped a sound physiological criterion may be derived, probably based on body temperature levels and circulatory responses. But even when a suitable criterion is agreed, further experiments to apply it to the complex mining conditions will take some time. In the absence of suitable information at present, it would be premature to make a definite and irrevocable statement regarding the level of permissible environmental limits for everyday work.

Remedial Measures

While gaps in our knowledge of man's response to heat obviously exist, there is available to us a considerable volume of information which may be utilized in a practical manner. Many industries have localized heat problems. To show the sort of advice that can be given, it is convenient to consider a typical but hypothetical example, where in-

TABLE 3. COMPARISON OF CONDITIONS OF WORK AND RECOVERY IN THE ROYAL NAVY AND IN MINING, AND THE LIKELY EFFECT THAT DIFFERENCES IN THESE CONDITIONS WOULD HAVE ON THE THERMAL LIMITS PROPOSED FOR USE IN THE ROYAL NAVY.

Factors which may affect limits	Conditions of work		Effect on Royal Naval Limits
	Royal Navy	Mining	
Rate of work	110 kcal/m²/per hr	165 kcal/m²/per hr	reduction
Exposure-time	4 hr	5–8 hr	reduction
Acclimatization	high	high (?)	no change (?)
Age	≯ 50 years	15% > 50 years	reduction
	20% > 40 years	40% > 40 years	(likely)
Posture	favourable	often unfavourable	reduction (?)
Type and pattern of work	favourable	less favourable	reduction (?)
Clothing	shorts	shorts (assumed)	no change
Thermal conditions for recovery	may be warm	usually cool	increase (?)
Practical limit	E.T. 27 °C	Probably less than 27 °C E.T.	

Effective Temperature values of about 27-28 °C (80.6-82.4°F) can be applied to mining conditions.

It seems likely from a comparison of this sort that if the accuracy of the naval limit is accepted, any limit set for mining must be lower than an Effective Temperature of 27°C, and in this way the environmental zone in which experimentation ought to be carried out is narrowed. This conclusion is to some extent supported by results of recent experiments on the decrement of physical performance of African miners at various temperatures; it is hoped that the results from these experiments will soon be published.

One of the main difficulties remaining, however, is to reach agrement on some acceptable criteria by which performance may be judged. The Physiological Research Unit of the National Coal Board is at present engaged on experiments from which it is

formation is sought on the length of time men may continue to work in specified conditions.

The information given:

(a) Climatic		(b) Non-climatic	
Dry-bulb temperature:	43.3 °C (110 °F)	Rate of work:	350 kcal/hr
Wet-bulb temperature:	30.9 °C (87 5 °F)	Clothing :	overalls
Air movement:	200 ft/min	Acclimatization:	nil
Additional radiant heat:	nil		

From the information given, along with an estimate of levels of skin temperature (available from the literature), an assessment may be made of the amount of heat exchanged betwen the body

and the environment through the various channels. Thus,

$$\left.\begin{array}{l} M = +350 \text{ kcal/hr} \\ C = +\ 99 \text{ kcal/hr} \\ R = +\ 80 \text{ kcal/hr} \\ E = -372 \text{ kcal/hr} \end{array}\right\} \text{Overall heat gain} = 157 \text{ kcal/hr.}$$

That is, heat is continually gained by the body, at a rate sufficient to raise the body temperature of a man weighing 76 kg (12 stone) by about 2·5°C/hr (4·5°F/hr). Thus, after 1 hour, rectal temperature would be about 39·5°C (103·1 °F). Some men may be incapacitated by the time that rectal temperature reaches 38·9 °C (102°F). Since there is no hope of reaching bodily thermal equilibrium, clearly the conditions must be altered.

If the air and wall temperatures alone are reduced to a value of 35-36°C (95-96·8°F) where little or no heat gain occurs by convection and radiation, the rate of evaporation will also be reduced, so that the body still has an overall heat gain of 60-80 kcal/hr. If the humidity alone is reduced, however, the increase in possible evaporative heat losses allows thermal balance with a wet-bulb temperature of about 27·8°C(82°F). Dehumidification of working areas is often impractical, or extremely costly, and if this is not possible, some other arrangement must be found to reduce the total heat load and allow a bodily heat balance. One obvious method is to reduce the body heat production, either by reducing the rate of work, or if this is set at a constant level determined by the industrial process concerned, by arranging bouts of work to be suitably interspaced with periods of rest. Thus in the example quoted, an overall rate of work of 350-157 = 193 kcal/hr may be achieved by working for periods of 25 min with intervening periods of rest of 35 min.

Before deciding on the best solution to the problem, the strain on the individual must also be assessed. The original conditions yield a P4SR value of over 6 L so that men would produce sweat at a rate of about 1.5 L/hr. This rate of sweating cannot be continued for long. As noted above, reduction of wet-bulb temperature to about 27.8°C (82°F) would allow a heat balance to be reached. But the resultant P4SR is rather more than 5 L, and sweat rates of this sort cannot be sustained either; so while in such conditions the heat balance equation is satisfied, the physiological strain would be too great to allow continued work. The customarily accepted P4SR value for sustained work is 3 L, for acclimatized men, but this value would have to be decreased for unacclimatized men. A realistic value for unacclimatized men might be about 2.5L. Even when the work is arranged in bouts, with intervening rest periods to give an overall rate of body heat production of 193 kcal/hr, the P4SR value is 3.5L, and in order to make good this discrepancy a reduction in the total duration of each day's work would be desirable.

A recommendation would therefore be made that unacclimatized men ought not to work for more than say, 5 hr daily, in bouts of 25 min, with intervening rest periods of 35 min preferably to be spent in cool surroundings. Other suggestions would be that such work ought to be carried out under medical supervision, that men over the age of 50 and obese men ought not to be employed, that ample supplies of cool drinking water should be available, that careful watch should be kept on the climatic conditions to ensure that they do not worsen, and that if work is to continue for more than a few days, salt should be given at a rate of about 5 g/day in excess of normal dietary salt intake.

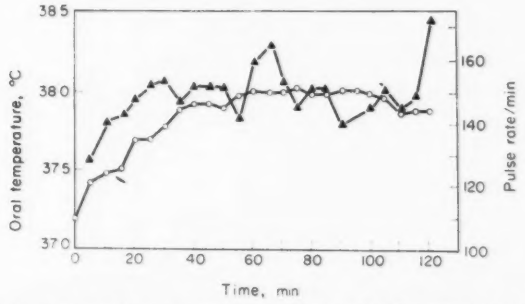

FIG. 3. Showing the oral temperature (o) and pulse rate (▲) of a man wearing a ventilated suit assembly, ventilated with 25 ft³/min or dry air (6–7 mm Hg vapour pressure) at 30°C (86°F) while exposed to an ambient temperature of 82°C (180°F). The subject stood throughout the exposure except at 55-60 min and at 115–120 min, when he worked at an estimated energy cost of 120-150 kcal/m²/per hr.

In many locations in industry the environmental conditions can be improved by simple procedures. Improvement of the ventilation will often reduce air temperature and humidity, particularly if cool air is piped to the working area. In the case of individuals who work more or less continuously in the same spot, a localized jet of cool air may be "sprayed" over that spot. In these ways, convective heat gains can be reduced and possible evaporative losses increased. High levels of radiant heat gain can be reduced by suitably insulating and shielding the source of radiant heat, or, if this is not possible, by providing the individual with reflecting protective clothing.

If very high air temperatures or humidities are unavoidable, then it may be convenient to protect the individual against the environment by using ventilated clothing assemblies. Basically, such assemblies comprise an impermeable overall with

suitable thermal insulation, and a separate supply of cool, dry air is used to ventilate the interior of the suit. The main drawback of such assemblies is that they restrict freedom of action to some extent. A suit which might be of use in industry has been described recently by LIND et al. (1959) who showed that with adequate ventilation to the assembly, men can maintain thermoregulation easily for periods of at least two hours in an ambient air temperature of 82°C(180°F), as shown in Fig. 3. If further assistance for thermoregulation is needed, the thermal insulation can be increased (this also makes the suit more cumbersome) or cool water can be sprayed on the outside of the suit. Since the wearer is provided with his own environment inside the suit, high levels of ambient humidity do not affect him. The principle of spraying cold water can also be used in an emergency to cool men not wearing ventilated suits. This method has been used in South Africa (Wyndham et al., 1959) to cool gold-mining recruits who find the heat stress of working underground too great.

A great deal of work remains to be done to evaluate the responses of industrial workers to heat. But although there are gaps in our knowledge of these responses, the information available at present is extensive and, properly used, can help to answer many specific industrial heat problems.

Summary

This paper is not intended to consider comprehensively all the aspects of man's response to work in hot environments, but rather concerns the effects that the main results of recent research have on our understanding of (1) the principles governing heat exchanges between man and his environment, (2) the importance of various factors which can affect these exchanges, (3) the accuracy of some well known indices of heat stress, and (4) the determination of "limiting conditions of heat" for different types of work. In addition, an example is given of the use of information at present available in answering specific heat problems in industry.

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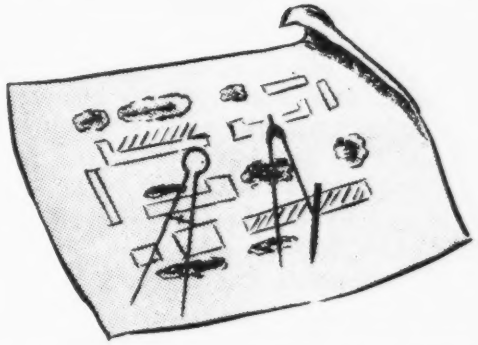
AIR POLLUTION CONTROL BY TOWN PLANNING



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Introduction

Air pollution control is practised in most large cities today. By introducing more efficient methods of combustion or suitable stack-cleaning equipment, it has often been possible to reduce pollution levels, even under pressure of expanding industrial development. The most notable example is in Pittsburgh (Department of Public Health, 1953) where the number of hours of heavy smoke diminished from 298 in 1946 to 16 in 1953. The observations were taken by the United States Weather Bureau from the top of a tall building in the downtown part of the city.

Although it is theoretically possible to scrub out nearly all obnoxious gases and particulates from a stack, there is an economic limit to the process. Recovery and disposal of the last 10 per cent of waste products can be very costly. Civic authorities do not wish local pollution ordinances to be so severe that industry is driven out of the area; in fact, many communities are attempting to attract new industry. A balance must therefore be found between added manufacturing costs and tolerable health, aesthetic, corrosion, and nuisance levels of pollution.

Within these terms of reference, then, cities are turning to town planning through the use of zoning by-laws. This generally has the support of industry, as well as the public, because it offers protection to the industrialist from the encroachment of residential areas. When a manufacturer locates in the country, a housing and shopping development soon appears near his plant, forcing eventually some form of pollution control.

Unfortunately, the atmosphere cannot be regulated in the same way as can a blighted slum area. Under certain meteorological conditions a plume of smoke will travel for many miles with little dilution beyond that which may have occurred in the preliminary, aerodynamic phase involving entrainment of air after the hot gases leave the source. It follows that a city cannot be divided into neat little compartments with respect to air pollution. Professional meteorological assistance is evidently required to select those areas that will minimize future pollution problems. This paper will be concerned with what shall be defined as "design criteria for air zoning". Does there exist a rational meteorological basis for making an operation decision on site selection?

There are, of course, other sources of pollution such as automobiles and household incinerators. However, town planning is concerned primarily with the location of industrial emissions; the following discussion will be limited to that type of pollution.

The air zoning parameters

In order to reach the best air zoning decision, a number of factors must be considered.

(a) The air pollution climatology of the area should be known. This will be considered in detail later.

(b) The allowable threshold concentrations of various gases and particulates should be known. What percentage of the time is a given concentration permissible? Medical authorities do not yet agree on the effects of long exposures to the relatively low concentrations that usually occur in urban atmospheres. However, they do agree on the harmful effects of extreme smog "incidents" such as occurred at London (Royal Meteorological Society, 1954) and at Donora (Division of Industrial Hygiene, 1949). In this connection, it must be known whether the same standards are to be applied to all parts of the city. Is the object of town planning to protect property values in residential areas or to protect the health of occupants of blighted tenements? The meteorologist must know where the emphasis is to be placed before he can prepare design criteria.

(c) A related problem is the population density distribution. In the case of site selection for nu-

clear power plants, this is often integrated into the analysis, based on the premise that ground level concentrations should be weighted according to the average number of people at different points down-wind. The population is either counted or else a theoretical distribution is assumed. For example, an Atomic Energy Commission study (1957) of an imaginary city uses the function,

$$P = 200\ R^{2.83}$$

where P is the number of persons within a radius R in miles of the centre of the city. Beyond the city limits, a uniform population of 500 people per square mile is assumed.

(d) The existing pattern of ground-level concentrations throughout the city should be known. The influence of new sources of emission can then be evaluated in relation to the present pattern. *Frenkiel* (1956), assuming no change in efficiency of abatement methods and assuming an orderly growth of industry and population in Los Angeles County, has predicted mean hourly concentrations for the year 1980 at a particular sampling point. His approach merits careful consideration by city planners.

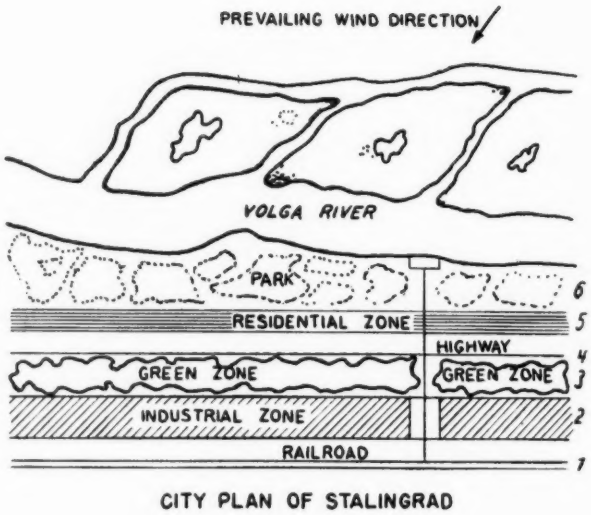
(e) The land available for industrial development is usually restricted by such factors as water supply, rail service, topography, the cost of real estate, etc. Air zoning is only one factor in town planning of land utilization. Hence, it will be weighted with other considerations, and the meteorologist may be asked to evaluate one site in comparison to another. This, perhaps, is a simpler question than that posed by Frenkiel (1956) because the answer does not involve a quantitative calculation of pollution levels but only a relative comparison of two sites.

Before commencing work on a meteorological study, it is necessary to define carefully the problem to be solved. The preceding discussion has made it clear that the initial step is a very difficult task in the case of air zoning. Permissible threshold concentrations (in relation to length and frequency of exposure) have not been clearly defined by medical authorities. The present pattern of pollution is probably not known very accurately. Finally, the type of new industry and the strength of its emissions cannot be specified.

The prevailing wind

If the wind blew steadily from one direction, there would be clear advantage in locating heavy industry on the down-wind side of a city; air quality in the residential areas would be greatly improved.

In some parts of the world the wind blows very persistently from one direction. It is then quite practical to use this approach to town planning. One example is given in Figure 1, a plan of Stalingrad (Kratzer 1956). When the prevailing northwest wind is blowing, industrial pollution does not affect the residential areas. As an additional safeguard, a green belt separates the two zones.



CITY PLAN OF STALINGRAD

FIGURE 1

Reproduced by the courtesy of the Journal of the Air Pollution Control Association, June, 1960.

The restless atmosphere is a great natural resource. The plan of Stalingrad illustrates how mankind can work with, rather than against, the weather.

The meteorological factors

In most parts of Canada there is no clear directional advantage to the wind. Except in cases of channeling by valleys, wind roses show rather flat distributions with perhaps a small surplus of southwest or west winds. The possibility exists, however, that poor dispersal conditions may be associated with certain wind directions. Veryard (1958), for example, has examined for London, England, all occasions in the last forty years of fog comparable with that of the smog of December 1952. He found 12 such cases of which 8 were associated with light easterly winds (the prevailing wind is westerly). It is therefore useful to consider the various meteorological factors and their effects on pollution.

A plume from an elevated stack first reaches buoyant equilibrium with its environment at some "effective" stack height. The plume is then transported downwind and is diluted by eddy diffusion.

For a given wind speed, the atmosphere shows a wide variation in its ability to diffuse pollution. When there is vigorous turbulence, the dilution

factor can sometimes be of the order of 10^{-6} within a few miles of the source. On the other hand, when the flow is nearly laminar, a plume may maintain its identity for distances of 30 to 50 miles.

There are seven mechanisms that can produce unduly high surface concentrations or depositions from elevated stacks.

(a) Gravity fall-out of large particles such as fly-ash. Modern industrial plants can successfully eliminate this nuisance at moderate cost through stack-cleaning equipment. It is therefore not regarded as a significant factor in site selection.

(b) Orographic intersection of the plume with higher terrain. If there is any choice at all, one should not locate new industry in a valley, particularly if there are residential areas on the sides of the valley. However, if such a site is necessary, local building ordinances should be designed so that stack heights and exit velocities and temperatures ensure effective stack height above the height of land.

(c) The classical inversion situation. An inversion (temperature rise with height) reduces turbulence and diffusion. It is caused by radiational cooling of the ground at night or by the advection of warm air across a cool lake or sea. Under such conditions, and over level terrain, the lateral spreading of a plume is within an angle of about 5° but the vertical diffusion is extremely small. The pollution is effectively "trapped" but it must be remembered that it is as difficult for the plume to spread down to ground level as it is for it to escape aloft. The inversion must therefore exist for many hours and be accompanied by rather light winds. The historical pollution disasters were associated with inversions lasting several days. Munn and Katz (1960) have considered a lengthy inversion at Detroit-Windsor.

(d) The fumigation situation (inversion aloft with lapse conditions below). The phenomenon was first described by HEWSON (1945). It may occur during the morning break-up of a radiation inversion or continuously along a coastline when an advection inversion disappears as warm air moves from cool water to heated land. Coastline sites must always be treated with suspicion in the absence of precise micrometeorological measurements.

(e) Aerodynamic downwash in the wake of the building. When strong winds are blowing, a turbulent vortex may form, causing the plume to curl down the side of the building. The effect is usually restricted to the plant property and can best be solved in the wind tunnel. Through the use of scale models, a certain orientation, shape of buildings, and stack height can be found that will minimize downwash. Except in combination with unusual orographic features, the effect is not regarded as significant in town planning.

(f) The looping plume. Under lapse conditions and with brisk winds, a turbulent eddy enclosing a puff of smoke can be brought down rapidly to ground level with little dilution of the pollution. This results in spasmodic bursts of high concentrations, each of which is of short duration. Increasing the height of the stack reduces the frequency of puffs but widens the area of influence. Munn and Katz (1959) have isolated the looping plume effect at a sampling station 5/6 mile from an elevated point source. It occurred under lapse conditions when the wind speed exceeded 11 knots.

(g) Rain-out and wash-out by precipitation. Although it has been established that rain is a natural cleanser of the atmosphere, exact quantitative relationships are not known. Correlations at Leicester (Department of Scientific and Industrial Research, 1945) indicate that up to 40 per cent of dissolved matter and up to 20 per cent of insoluble matter is brought down by rain. Theoretical treatments given by Chamberlain (1953) and others require too many simplifying assumptions. One of the complications is that wash-out is not uniform. A brief shower at the beginning of a period of continuous rain might be of over-riding importance. Presumably precipitation cannot be included in quantitative design criteria, although it would be of some interest to compare wind roses under precipitation conditions with conventional wind roses.

Design criteria

Despite the complexity of the problem, a number of papers have appeared recently suggesting various criteria for industrial zoning. One of the difficulties in the past has been the lack of suitable field observations of inversion frequencies.

Leavitt (1960) has used temperature measurements from a 215 ft. tower to obtain town planning information for Tulsa, Oklahoma. Munn (1959) has presented some inversion data from television tower WJBK, Detroit. Singer (1960) has proposed a new objective method for site evaluation. Holland et al (1960) consider the problem as it pertains specifically to Los Angeles county. As a final example, (Kolbig 1959) has put forth a German viewpoint on the subject.

The calculation of the distribution of ground-level concentrations arising from an elevated point source is a mathematical problem of some complexity. A number of models have been proposed, the two most popular being those of Sutton (1947) and Cramer (1959). Gifford (1960) has provided

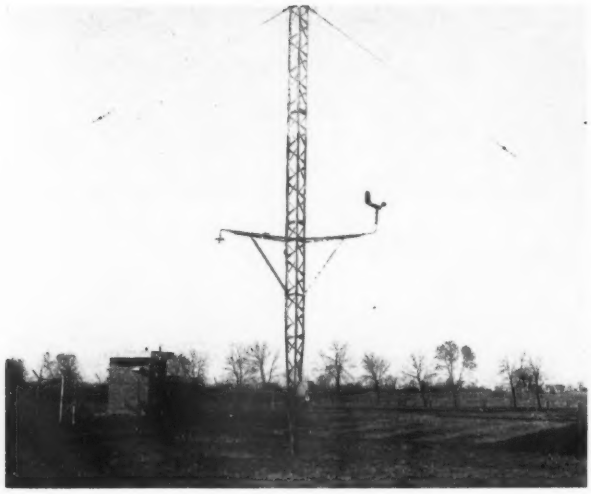


FIGURE 2
The meteorological tower, Central Experimental Farm, Ottawa. *Photo by Dept. of National Health & Welfare.*

a useful comparison, together with a summary of values of the parameters for different terrains and stabilities.

The net result of these and other studies is that there is no universal answer to the problem. Each city or site must be considered separately; the effect of a river or a ridge of hills may be profound on transport and dilution. In particular, where a city is located on a lake, the break-up of the lake inversion as it moves inland may be the most important factor.

No attempt will be made in this paper to critically examine the mathematical theories or to suggest a "best" set of meteorological design criteria. It is sufficient to say that the Meteorological Branch of the Department of Transport and the Occupational Health Division are engaged in cooperative studies of the problem.

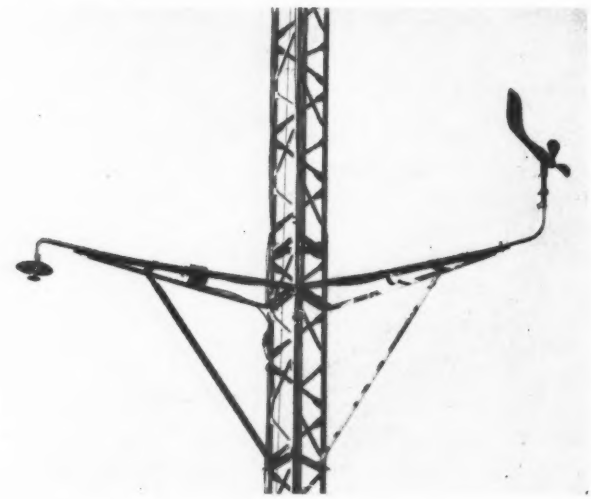


FIGURE 3
Meteorological tower showing instrumentation at 20 ft. level. *Photo by Dept. of National Health & Welfare.*

In order to obtain meaningful answers, regular observations of inversion frequencies must be accumulated. This is being done in Ottawa, for example, by the Occupational Health Division with a 200 ft. meteorological tower located at the Central Experimental Farm. Figs. 2 and 3 show the tower and the instrumentation at the 20 ft. level.

Conclusion

Many Canadian cities are relatively young; many do not yet have important air pollution problems. Nevertheless, if the present rate of industrial expansion is projected fifty years ahead, who can say what restrictions may be necessary.

Intelligent industrial zoning based on meteorological considerations is a very attractive goal. Although the problem is difficult, it appears to be a very worthwhile field of research.

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Chemical Occupational Hazards

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Director, Occupational Health Branch,
Saskatchewan Department of Public Health,
Regina, Sask.

A considerable price, in the form of human lives and health, has been paid for the rapid technological and industrial advances of the past 150 years. Outlined in this article, are some of the more dramatic events of interest to chemists.

In 1815, Professor Gehlen, a Munich chemist, inhaled some arsine and subsequently died from its effects. Organic mercury compounds are often thought to be a modern development in chemistry but as long ago as 1863 two laboratory technicians at St. Bartholomew's Hospital in London died following exposure to di-methyl mercury. Soon after the development of the Mond process for nickel refining 37 workmen who were exposed to the gas nickel carbonyl were taken ill and two died.

X-rays have also exacted their toll. Tiraboschi, an Italian radiologist, who died in 1914, was the first of over 100 persons to die by 1920 as a result of exposure to ionizing radiation. The tragic story of the New Jersey radium dial painters is perhaps well known. Sixteen painters and four of the plant chemists died in the 1920's, including the firm's technical director Dr. von Sochocky.

The introduction of tetra-ethyl lead into gasoline in 1923 demonstrated the hazardous nature of this chemical as 149 cases of encephalopathy, 11 of which were fatal, occurred. Even stenographers have not been immune to the effects of toxic substances. In Alberta in 1943, two girls who worked in a warehouse where di-ethyl mercury was stored were fatally poisoned as a result of the slow vaporization of this organic compound, building up a toxic concentration in the work area.

Chemists are naturally interested in knowing if there is any relationship between toxicity and chemical structure. While there are some trends related to structure, by and large the toxicity, based on formula, is unpredictable. The moral to this is that a chemist developing or using a new substance should always consider it to be toxic until there is good evidence that it is not so.

A few examples will serve to illustrate some of the observed relationships and the limitations of this approach. The higher members of the alcohol series are more toxic than the lower ones, the exception to the rule being methyl alcohol which is well known to be more toxic than ethyl alcohol. Although the higher alcohols are potentially more toxic, their actual effect on the body is limited because they are increasingly insoluble in body fluids. The replacement of a carbon atom by a chlorine atom can have different results in aliphatic and aromatic compounds. As a general rule the introduction of chlorine into the aliphatic compound increases its toxicity while the reverse applies to the aromatic compounds. Methyl chloride is much more toxic than methane which only has asphyxiation properties; increasing the chlorine atoms through methylene chloride, chloroform and carbon tetrachloride increases the toxicity. The addition of chlorine to the organic sulphur compounds usually increases the toxicity — ethyl sulphide, monochlorethyl sulphide, dichlorodiethyl sulphide (mustard gas). On the other hand, the addition of chlorine to benzene, which is a fairly toxic substance, produces benzyl chloride and reduces toxicity.

Hydroxyl groups added to both aliphatic and aromatic compounds will usually increase toxicity. Methyl alcohol is more toxic than methane, and phenol, resorcinol and pyrogallol are progressively more toxic than the parent benzene.

The actual structure of the same chemical can influence its toxicity. Iso compounds are usually less toxic than normal compounds, examples being isopropyl and isobutyl alcohols. Another example of the influence of structure is benzene hexachloride, the isomer being 60 times more toxic than the other four known isomers. This isomer of BHC is widely used as an insecticide.

While minor modifications of certain chemicals can alter toxicity the reverse situation is also found. Chemicals of widely differing constitution can have the same effect in the animal organism. Hydrocarbons, alcohols, ethers, sulphones and amines all have narcotic properties, probably because they all

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modify in some way physico-chemical conditions in the cells.

Toxic substances may gain entry into the body by ingestion, inhalation or through the skin. Because the latter mode of entry is not widely known, some time will be devoted to discussion of the trans-epidermal and trans-follicular routes of absorption. The trans-epidermal route involves the passage of the substance through the superficial barrier of the lower stratum corneum. Substances passing trans-follicularly enter the body through the hair follicles. Lipid soluble substances are those absorbed via the epidermal route — phenol, phenolic derivatives, hormones, vitamins A and D, free organic bases such as strychnine and nicotine. Both groups of insecticides — the organic phosphorus and the chlorinated hydrocarbon — are absorbed via this route. Other compounds include: benzidine, aniline, naphthylamine, dinitrophenol, nitro benzene, nitro glycerine, tetra-ethyl lead, carbon bisulphide, hydrocyanic acid and the rocket propellants the boron hydrides. Absorbed via the follicular route are electrolytes and some of the heavy metals. A classical example of the latter group is mercury which for centuries was used as an inunction for the treatment of syphilis.

A summary of the toxic effects of some commonly used chemicals will probably be of interest. Arsine is rarely deliberately produced in industry, rather it is an unwanted by-product of the pickling of metals. A few cases of poisoning occur in industry every year: arsine acts on the red blood cells to cause haemolysis, or breaking up of the cell membrane, with resultant jaundice, anaemia, kidney damage and perhaps death.

Fortunately benzene has to a large extent been replaced in industry by other safer solvents but it still appears occasionally in mixtures of solvents or as an impurity in sufficient concentration to present a hazard. Benzene has a narcotic effect but perhaps more important is its chemical effect on bone marrow depressing its activity, with a resulting reduction in red and white cell production.

In England, in some of the old factories where rubber vulcanization was carried out, bars across the windows of the upper floors can still be seen. These were originally placed there to prevent employees throwing themselves out of the windows when they developed the acute mania which is one of the symptoms of carbon bisulphide intoxication. Other effects are a feeling of well being, bizarre dreams, mental deterioration and respiratory paralysis.

Hydrogen sulphide will quite rapidly dull the sense of smell so that the individual soon becomes unaware of the intensity of the exposure. Irritation of mucous membranes occurs with low concentrations; larger concentrations produce rapid respiratory paralysis and death.

The mad hatter in "Alice in Wonderland" was a typical case of inorganic mercury poisoning. The mercury used in the carrotting process to produce felt is responsible. Features of intoxication are embarrassment at being watched, excitement, bad temper, tremor and inflammation of the gums. Careless handling of mercury in laboratories can result in sufficient mercury being present in cracks, crevices and behind the benches to produce potentially toxic levels of mercury in the working environment.

Organic mercury compounds, used as seed dressings, vary in their toxicity; the methyl and ethyl compounds are much more toxic than the propyl and tolyl compounds. The effects are on the central nervous system causing gross inco-ordination of movement and partial blindness.

Organic lead in the form of tetra-ethyl lead is highly toxic. Because of rigid industrial hygiene precautions hardly any cases of poisoning have been recorded since early disasters demonstrated the necessity for special handling precautions and thorough education of the exposed workers regarding the hazards. The effects are mainly on the central nervous system.

Phosgene and nitrogen dioxide can be grouped together because their effects are similar. After inhalation of the gases there is some immediate respiratory irritation but the appearance of more severe effects of pulmonary oedema is delayed for a few hours.

First Aid

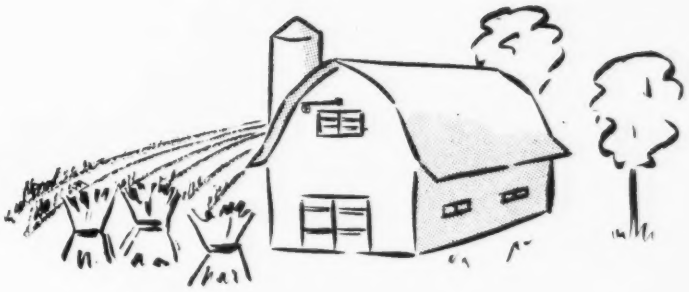
Toxic substances or caustics on the skin should be flushed off with copious supplies of water. Damage to the skin by over vigorous washing should be avoided as it facilitates absorption.

Provided the patient is conscious, the general rule for the treatment of ingested poisons, with the exception of strong acids or alkalis, is to induce vomiting either by tickling the back of the throat with a finger or giving an emetic such as salt water (two tablespoons of common salt to a glass of water). The danger with the strong acids or alkalis is that vomiting will rupture a partly corroded stomach. Here the objective is to dilute and neutralize or absorb the poison so plenty of water is given, an appropriate weak neutralizer is added or raw egg or flour given in water.

If toxic gases are inhaled immediate rest is im-

(*Continued on page* 23)

Occupational Health *in* *Agriculture*



by FRANKLIN H. TOP, M.D., M.P.H., Iowa City.*

Until recently, "industry" excluded farming. The farmer is an independent operator, often working alone, or sometimes cooperatively with his neighbors, employment of hired help being the exception rather than the rule. The farmer has his home and workshop together. Concerning the industrial worker today we think in terms of the following: fringe benefits, double pay for overtime, triple pay for Sunday work, desire for a 35-hour work week, 8 regular holidays, and unemployment compensation. All of these terms are applicabe to industry and organized labor, but are not commonly thought of by the farmer and, if so, in many instances are unwanted.

However, a change is taking place, in that little farms (80 acres and less) are being abandoned or combined to produce farms of 160 acres to a section in size. The market is too competitive for farm products to be produced on small acreage. The change has been hastened by technological advances in machinery which make it unprofitable to engage in farming under 160 acres. The changes are not all due to improved machinery; there is availability of better fertilizers, of farm chemicals such as pest destroyers, and of growth stimulators such as hormones and antibiotics, which make large farm operation more possible and economical.

The title "Occupational Health in Agriculture" is an example of a relativey new concept, for a decade or two ago "occupational health" as a term was not frequently used, but "industrial hygiene" was far more common. Farming is definitely an industry and agriculture today is big business. Here are some facts[1]:

As of Jan. 1, 1959, total farm assets were $203,000,000,000 and the liabilities only $23,333,000,000. The assets are equivalent to more than two-thirds of the value of all stocks of all corporations on the New York Stock Exchange.

The average American farm represents an investment of about $27,000 per worker, compared with an average of about $15,000 per worker in non-farming industry.

The marketing of food products supplied by the nation's farmers was a $36,900,000,000 business in 1958.

Over 22,000,000 workers are employed in agriculture and agricultural industries. This is more than one-third of the total U.S. employment.

On United States farms, there were 4,750,000 tractors, 3,060,000 trucks, 4,260,000 autos, 725,000 milking machines, 760,000 corn pickers, and 1,060,000 combines. For machine operation, farmers buy fuels equal to 15,000,000,000 gallons of crude petroleum — more than any other single industry.

The farmers' investment in machinery is twice as much as that of the entire steel industry and

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NOTICE OF CONFERENCE

The Third World Congress on the Prevention of Occupational Risks will be held in Paris, Palais de Chaillot, May 22nd—27th, 1961.

Interested organizations are invited to enquire concerning the possibility of displaying posters, films, etc., at this Congress. Additional information may be obtained from:

The General Secretary,
c/o I.N.S.
9 Avenue Montaigne,
Paris 8, France.

five times as much as that of the automobile industry.

The health of the farm worker has not been considered or studied as has the health of the worker in other industries. "Industrial hygiene" as part of the greater term, "occupational health" is of old vintage and came of age during the past half century. Great things have been accomplished by industry in the matter of care of the worker. Many people feel that the farm should be a very healthful atmosphere in which to work, and so it is, but this is offset by the numerous hazards which confront the farm worker. Among these are the zoonoses, farm chemicals, accidents, allergy, and sanitation.

Zoonoses

Zoonoses are infections of animals which may be transmitted to man, and some 80 have been described as occurring in the United States. Few animal diseases are reportable, and the impact of the zoonoses is not yet fully appreciated. The health of the farmer and of the consumer of farm products is affected by control of infection in animals on the farm. Zoonoses appear important enough to demand adequate reporting of animal diseases, verification of diagnosis, if possible, and collection and analysis of data resting on these reports. An attempt is being made to do this through the efforts of the Agricultural Research Service of the United States Department of Agriculture, which publishes monthly the "Animal Morbidity Report," which lists some 13 diseases reported by all 50 states, the District of Columbia, Puerto Rico, and the Virgin Islands.[2] Of course, the reporting is not complete, but a beginning has been made. By this means, incidence data can be obtained, adequate control measures applied, and efficacy of control measures determined. The key people in the prevention of the zoonoses are veterinarians and general practitioners. Each should immediately report disease when and where it is found.

Making the acquaintance of the veterinarian in a community will often lead to a clue which makes a diagnosis possible in a disease which has defied assessment of the history, examination, and laboratory tests in a fever of undetermined origin. Any of the following diseases fall in this category: Q fever, leptospirosis, brucellosis, psittacosis, tularemia, and tuberculosis, among others.

Signs of cooperation are evidenced by programs on these subjects planned by two county medical societies in Iowa within the past year. At one, the medical society was host to dentists, pharmacists, and veterinarians; at the other, to veterinarians. Each of these two societies does this once a year. At each of the recent meetings several physicians spoke of the value of the veterinarian to him and to his community.

Farm Accidents

Accidents play a leading role as the principal causes of death for people in all occupations. From ages 1 through 34 by five-year increments the leading cause of death is accidents, and in farm accident compilations[3] made by the National Safety Council for 1959, farming as an industry ranks third in the number of deaths by accidental means — only mining and construction work rank above it. Motor vehicle accidents are responsible for the greatest share of the deaths from farm accidents.

Work in a plant may be exacting and monotonous, but there is opportunity for the coffee break, and the hours at work are 8 per day for 4 or 5 days, with the week end off. During the growing season, the farmer is not on a 35- or 40-hour week, and, although he has the opportunity to take breaks while working with farm machinery, he frequently does not take them, particularly when the vagaries of weather make it appear desirable to complete the job. When farm machinery was horse-drawn, periodic rest periods were necessary for the horses, and the farmer, of necessity, also rested. Now he can demand of his machinery work which takes him into the night, sometimes as long as 16 hours with only a lunch break. Many examples come to mind. I cite one: A farmer working all morning without a mid-morning snack came in for lunch and found that his wife had not yet prepared the meal. Disgruntled, he took a glass of milk, stomped out of the house, and went back to work. Within an hour he was involved in a tractor accident that led to loss of a hand.

In how many instances in industry would one expect a worker to hold a young child in his arms while running a lathe or any other piece of machinery; to allow a child of 8 or 10 years to ride in the cab of a crane or on the seat beside the driver of an earth mover; or to permit a child to stand on the scaffold with his bricklayer father? Yet the farmer evidently has no qualms about carrying a 2-year-old on his lap while driving a tractor in the field or on the highway, allowing a 10-year-old to drive a tractor or car on the farm premises, using the highway for travel between field and the farm home, or allowing the boy to cross a busy highway to reach home. The difference in attitude may be the impress of the stringent rules in force in most manufacturing plants, but the general philosophy of the two groups may also differ. The average industrial worker wants to earn his pay, keep the boss happy, and get a promotion; none of these de-

sires are paramount to the bulk of farm operators and workers. The farm worker's idea is to get the job done as quickly as possible, and this invites improvisation and unnecessary risk-taking involving health and accident potentials.

There are other penalties which might be considered in relation to the hazard of working with farm machinery. For example, is the farm operator in a comfortable upholstered seat while driving his tractor or other piece of machinery? Unfortunately not, and back and kidney disorders are not uncommon. Don't forget the shortcuts the farmer utilizes while hurrying to get the job done which may lead to tipping of the tractor sideways or backward. A person becomes careless when tired. Have you ever seen a farmer standing on his tractor while driving? What if he hit an unseen boulder or chuckhole? Is it any wonder he gets tired of sitting for long periods of time? Hence, he stands, and the only place to stand is on the axle, and this gets hot. Furthermore, on encountering an obstruction he is in more danger of losing balance than when sitting. The problem is well stated in these excerpts from a letter of a farmer seeking help which was placed in our hands:

Briefly, it seems to be the vibration that bothers my back the most. Now I can ride in a car and get along okay, but on a tractor there is not enough provision to absorb the vibration and jolts. I use tractors equipped with Monroe hydraulic seats and extra foamrubber padding that I have put on.

The car has soft tires, soft springs, and then the padded seat, all of which apparently absorb the vibration. Has anyone ever tried mounting a seat on the tractor in such a way that coil springs or rubber hangers or air cushion would also absorb the punishment before it gets to the seat? I have tried wearing a wide leather belt such as truck drivers sometimes use, and at the present I am trying a big steel brace which doesn't help a bit. This brace came as the result of a tractor injury last fall.

About the only way I can stay on a tractor is to stand up, and apparently my legs help absorb the vibration. I have talked with a lot of farmers and most of them have this same problem to a greater or lesser degree. Your help and consideration will be very much appreciated.

Farm machinery is being improved, but there is a long way to go. In the Institute of Agricultural Medicine at Iowa we are attempting to help in this field by getting into the matter of design of tractors and other farm machinery. An an example, last December a local physician informed the Institute safety engineer of the fact that three cornpicker accident victims who had been injured on the same type and make of machine were in the same hospital at the same time. Investigation showed a fourth man had been a victim of the same make and type of machine within the month. Upon investigation of their physical injuries and a survey of the equipment involved, it was obvious that corrective measures were needed. The manufacturer of the cornpicker involved was supplied with our findings and photographs of his tractor-mounted cornpicker with unshielded gears. Six months later plans had been made up to equip all new cornpickers of this manufacturer with shields to protect the operator from the hazard uncovered in Iowa; also, arrangements were made for every dealer throughout the United States and Canada to receive a supply of the shields, which were to be made available for application on any previous model at a nominal cost.

There is also a serious problem to overcome to educate the farm worker. The busy farmer is an important man. He is in a hurry, and safeguards are not replaced when removed or they are too much bother or too unhandy to bear with, so they may be removed shortly after purchase of farm machinery.

Farm Chemicals

Hormones added to feeds aid in faster growth of livestock such as chickens, turkeys, swine or cattle. Is there danger in handling feeds with added hormones? There may be. Feed mill employees and farmers who add hormones to their feeds may develop nonmasculine characteristics if they or mill operators become careless.

Antibiotics are added to feeds to hasten growth of livestock and to prevent infection. Contact of the farm worker with antibiotic additives may sensitize him and prevent their use when he becomes ill and needs them.

Insecticides and pesticides are being used increasingly on the farm, and, unfortunately, the worker may be a victim of their use, particularly when he puts together the spraying equipment himself. Even when the sprayer is manufactured and apparently satisfactory, the act of spraying may not be, particularly when the vicissitudes of the weather, such as humidity and wind, are unfavorable. Severe headaches, gastrointestinal upsets, loss of time at work, and contact dermatitis are some of the findings.

Millions of bushels of grain are stored on Iowa farms yearly and insect control in such storages is a critical problem. In a nearby Iowa county, handling of grain fumigants resulted in illness of the handler. The widespread use of carbon tetrachloride-ethylene dichloride fumigant is under study at several county Agricultural Stabilization and Conservation storage sites where its concen-

trated use may be more easily noted. Recently, the Institute prepared a technique for a simple field sampling of chemical exposure to this mixture which was tested during the 1960 fumigation period.

Environmental Health

The farmer is not only an independent operator, but he does not share the community services that the city worker does . He must provide for water for personal and livestock use — the same source sometimes serving both purposes. He must also provide for the disposal of human and livestock excreta. He has, therefore, the making of sanitary problems which affect his health and that of his family. How often is the farm family's drinking water tested? How close is the cesspool or outhouse to the water supply? to the feedlot?

Farm ponds have been increasing in number at a great rate in many parts of the country. They may be used by animals in the field as a source of water supply and sometimes as a source of water for the family itself. In many instances the farm pond is used for swimming and other recreational purposes. Here is an opportunity for exposure to leptospirosis and some of the other zoonoses. Additionally, studies in Iowa have shown that some farm ponds have briefly contained a higher level of radioactive material from fall-out than is considered safe by present standards. This has resulted from continental atomic weapons testing. This has not happened often and not since the testing has been discontinued, but fissionable materials with long half-lives are likely to find their way into stagnant farm ponds because they drain the runoffs from the surrounding land.

Allergy

Dusts and pollens are encountered on the farm in great numbers. Sensitization may occur and this may lead to chronic bronchitis or asthma. Plant spores, animal dandruff, dusts and inhaled fumes or solvents are frequent offenders. Continued exposure may result in the necessity of termination of farm work.

Problems Evaluation

It is obvious from the foregoing that there are problems peculiar to farming as an industry. Regular medical care is not lacking for rural citizens, but attention to the farmer as a worker with peculiar problems and hazards of his own has left much to be desired. What is being done about the problem? Little as yet, but a beginning has been made. An attempt to improve the situation occurred through the establishment of Institutes of Agricultural Medicine. The first one was established in Poland 10 years ago. The one at the University of Iowa was established late in 1955, and in 1958 the third was established in connection with the University of Tours, France. Recently a Zoonoses Center was established at the University of Illinois. Progress is being made.

In Iowa, as in many other states, there is a university heavily emphasizing agriculture, as well as one not so oriented. No conflict in goals has been encountered. The Institute is interested in all things which bear on the health of the farm worker. There has been splendid cooperation from Iowa State University and the Deans of Agriculture and Veterinary Medicine are members of an advisory committee of the Institute. The Institute administratively is a part of the Department of Hygiene and Preventive Medicine of the State University of Iowa at Iowa City.

Service is not the aim of the Institute of Agricultural Medicine at the State University of Iowa; the aim is, rather, to recognize problems and attempt their solution. As an example, leptospirosis of the pomona type, which is a disease of cattle and swine, was reported in man in Iowa once or twice a year prior to a study begun in the Institute using blood sera sent to the State Laboratory for aid in diagnosis of an unexplained fever. Within two years, 40 sporadic cases were uncovered, and in August, 1959, a "swimming hole" epidemic of some 40-odd cases was studied. Five creeks and the Cedar River were implicated. Besides leptospirosis, attention is being given to Q fever, toxoplasmosis, and ringworm; to the farm pond content of nitrate and fissionable materials; to a method for quick determination of toxicity of farm chemicals for human tissues; to the risk of use of hormones in animal feeds; to farm tractor highway accidents; to farm tractor redesign; to excessive noise exposure connected with farm machinery in operation and to grain fumigation hazards.

Maladies of agricultural causation can be expected to occur more and more frequently in industrial medical practice. Currently 30% to 40% of farmers work in industry, and their number is increasing. These "weekend farmers" must be medically sound and they also represent a unique potential in such areas as fatigue, the shift syndrome, cumulative and synergistic, chemical exposures, injury aggravation, and others.

Many more problems could be cited, and to date the surface has just been scratched. It is our hope to develop a respectable attempt at identifying and at solving other problems which beset the farm worker. This, as we view it, is an attempt to give farm workers the same prerogatives in occupational health that their brethren in industry now enjoy.

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CHEMICAL OCCUPATIONAL HAZARDS

(*Continued from page* 18)

portant, a watch being kept on the person in case artificial respiration is required.

The safety shower provides the best first aid treatment for severe contamination of the skin with toxic or caustic substances. Soap can be used to wash the offending agent from the skin but over vigorous scrubbing is to be avoided because of the risk of facilitating the trans-epidermal passage of the substance.

The Saskatchewan branch of occupational health has the responsibility to protect and promote the health, at work, of all gainfully employed persons whether they work in industry, mines, agriculture, commerce or the professions. A well equipped laboratory enables the occupational health branch to investigate fully any potential health hazards in any work environment and subsequently advise management regarding any precautions which need to be taken to prevent damage to health.

OTTAWA
Queen's Printer and Controller of Stationery
1961

OCCUPATIONAL HEALTH REVIEW

"The program of the Occupational Health Division is concerned with service, research and education in the field of Occupational Health, and of Air Pollution in Canada.

The Division's activities include, environmental and clinical surveys, laboratory and consultative services; the promotion of teaching and research, and the publication of informative and educational material".

A QUARTERLY PUBLICATION